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Banana pests and diseases spread to higher altitudes due to increasing temperature over the last 20 years

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In this study, we established changes in minimum and maximum temperature over the past 20 years, and how these changes are likely to affect the status of key banana pests and black Sigatoka disease in main banana cropping systems. A survey was conducted at elevations of 1200, 1400, 1600 and 1800 m above sea level in 13 sites previously used in 1992/1993. Mean monthly minimum and maximum temperatures at different elevations were computed between 1991 and 2013 and used to determine the temperature change. Data was collected on weevil damage, nematode populations and black Sigatoka severity. Changes in weevil damage, nematode population densities and black Sigatoka severity were determined. Pearson's correlation analysis was used to establish relationship between minimum and maximum temperature change, changes in weevil damage, black Sigatoka severity and nematode population densities at different elevations. Results show that minimum temperatures in sites above 1400 masl increased by 1°C over the 20 years. Key banana pests and black Sigatoka disease were observed at elevations where they had not occurred before. Change in black Sigatoka disease, *Rhadopholus similis, Helicotylenchus multicinctus* and *Meloidogyne* spp. positively correlated with change in both temperature but change in banana weevil's damages positively correlated with maximum temperature.

Key words: Temperature change, banana weevils, nematodes, black Sigatoka disease.

INTRODUCTION

Global warming presents a challenge to agricultural industry. The productivity of the industry dependents on climate because temperature, light and water are the main drivers of crop growth (Olesen and Bindi, 2002; Colwell et al., 2008). Similarly, plant diseases and pest infestation are influenced by climate (Das et al., 2011; Rosenzweig et al., 2000). The survival, propagation and dispersal of plant pests and pathogens are significantly influenced by the environmental conditions (Agrios, 1997). For instance, climate change likely influence the distribution,

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incidence and severity of plant pests and diseases (Rosenzweig et al., 2000). Severe weather events greatly contribute to the emergence of plant diseases in new locations (Anderson et al., 2004). There is a greater likelihood that invasive diseases will become established, as climate change allows some plants and pathogens to survive outside their historic ranges (Harvell et al., 2002). It is also widely agreed that in a changing climate, pests may become even more active than they are currently, thus posing a threat of greater economic losses to farmers (Coakley et al., 1999; Fuhrer, 2003). Higher temperature, increased humidity and greater precipitation, on the other hand, likely results in the spread of plant diseases (Rosenweig et al., 2001), as wet vegetation promotes the germination of spores and the proliferation of bacteria and fungi, besides influencing the life cycle of soil nematodes and other organisms (Rosenweig et al., 2001).

Geographical distribution of plant-parasitic nematodes is influenced by host availability, soil type and climate (Boag et al., 1991). Soil temperature and moisture are the key climate variables that affect nematode abundance. Soil temperature is generally considered to be a limiting factor for plant parasitic nematodes and probably explains why certain species have not become established in areas that otherwise might be suitable (Lahtinen et al., 1988). Insects are cold-blooded organisms and temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival and reproduction (Bale et al., 2002). It has been estimated that with a 2°C temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani, 1998).

Just like any other crop, banana production is also constrained by a number of pests and diseases. For example in Uganda, bananas are grown in wide range of environmental conditions (Zake et al., 2000), but it was highlighted that black Sigatoka disease, root burrowing nematodes (*Rhadopholus similis*), and the banana weevils (Gold et al., 2004) were the key banana disease and pests. This was based on the diagnostic survey conducted between years 1992 and 1993. The yield losses associated with these key banana pests and diseases are 18 to 47% due to black Sigatoka disease (Tushemereirwe, 1996), up to 45% due to banana weevils (Rukazambuga, 1996; Gold et al., 2004) and 30 to 50% yield losses in East African Highland bananas due to nematodes (Speijer, 1999; Kajumba and Speijer, 1996).

These important banana pests and disease were mainly restricted to elevations between 1000 and 1300 masl (Tushemereirwe, 1996; Kashaija et al., 1994; Abera et al., 2007). This study was therefore conducted to assess how key banana pests and disease are likely to be influenced by temperature changes within 20 years in main banana growing areas of Uganda. This may be a basis for designing and deploying new banana disease and pest management strategies to account for epidemics newly established in higher altitude areas.

MATERIALS AND METHODS

Sites

Thirteen sites, representing the major banana growing regions of Uganda, were selected using a stratified random sampling based on UNEP and CIAT data bases for length of rainy season, elevation and population density (Tushemereirwe, 1996; Speijer et al., 1994; Kashaija et al., 1994). The sites represented four different altitudes where East African highland bananas are mainly grown in Uganda, namely 1200, 1400, 1600 and 1800 masl. These were the same sites that were sampled 20 years earlier to have comparable results. In each site, five banana plantations that were at least 10 years old were randomly selected for the study. A total of 260 banana plantations were surveyed.

To assess the effect of changes in temperature on the key banana pests and disease, data was obtained on the following parameters: daily minimum and maximum temperatures, banana weevil assessment, nematode assessment and black Sigatoka disease.

Temperature data

Daily minimum and maximum temperature data recorded at weather stations in Namulonge (1200 masl), Mbarara (1400 masl), and Kabale (1800 masl) over 20 years period were retrieved and used in further analysis.

Weevil assessment

Corm damage was assessed on 15 plants of recently harvested East African highland bananas in every selected banana plantation in all the 13 study sites. The percentage of tissue consumed by the weevil was estimated according to Rukazambuga (1996). The method involved making cross sections at the base of the pseudostem and 5 cm below the base, representing the upper and lower sections respectively. For each cross section, weevil damage was assessed for the inner (central) and outer (cortex) sections of the corm using a standardized scoring system. The average of the upper and lower outer portions presented damage in the outer (cortex) section of the corm (XO), while the average of the upper and lower inner portions presented damage in the inner (central) section of the corm (XI). Therefore, the average of inner (XI) and outer (XO) percentage damage presented the total damage of the plant (XT).

Nematode assessment

Banana root samples were collected from 15 recently flowered plants from an excavation of 20 cm wide, 20 cm long and 30 cm deep, starting from the corm of the selected plant in every selected banana plantations in all the 13 study sites. Root samples were collected for nematode extraction and identification. Nematodes extraction was done using Baermann funnel method with slight modification according to Namaganda (1996). Root samples were washed free of soil particles, chopped into 1 cm pieces and thoroughly mixed. Sub-samples were macerated in a kitchen blender for 4 s using a one Sanyo blender (model sm 162006 270

W). The extract was poured onto a sieve in a pan-pie dish, washed with tap water to dilute the phenolic compounds and incubated overnight. It was then poured into 100 ml jars and kept on a bench or in the refrigerator (10°C). Nematode species were morphologically identified under a microscope. The density of number of nematodes per 100 g of roots was then determined using the method of Fortuner and Mern as described by Adiko (1988).

Black Sigatoka disease assessment

Coexistence of black sigatoka, *Cladosporium speckle* and yellow sigatoka makes symptomatic identification of black sigatoka difficult. Position of the youngest leaf spotted with leafspot symptoms was used to indicate leafspot severity (Stover and Dickson, 1970). Total number of functional leaves (TL) and youngest leaf with spots (YLS) was recorded in 30 recently flowered plants in every selected banana plantations in all the 13 study sites. This represents severity of leafspots rather than black sigatoka as unambiguous diagnosis of leafspots using symptom alone is not possible. Leaf samples were therefore collected and taken to the laboratory. DNA was extracted from the leaf samples using CTAB protocol (Maguire et al., 1994) and then amplified using PCR with MF137 primers with approximate amplification product of 1000 bp in size with DNA from *Mycosphaerella fijiensis* to confirm the presence of black Sigatoka disease at the different elevations.

Data analysis

Temperature

Mean monthly minimum temperatures for the period of 1991 to 2013 was computed from data obtained from weather stations at different elevations. The minimum monthly temperature for the period between 1991 and 2013 at different elevations was computed using XLSTAT statistical software (Addinsoft, 2009). These were then subjected to regression analysis to determine the temperature changes at different elevation between 1991 and 2013.

Data on the total cross-section damage (XT) for the year 2012 was combined with that from the diagnostic survey for the year 1993. These were later subjected to analysis of variance using XLSTAT statistical software (Addinsoft, 2009), to determine the significance differences in the banana weevil corm damage levels at different elevations for the two diagnostic surveys, that is, 1992 to 1993 and 2012. The mean total cross-sectional damage at different elevations for the two surveys, were separated using Fisher (LSD) test at 5% level of significance.

The nematode numbers were subjected to logarithm transformation and analyzed with XLSTAT statistical software since the preliminary checks showed that the nematodes were not normally distributed. Means for nematodes populations per 100 g of root samples at different elevations was computed and then compared with the findings of Kashaija (1996) diagnostic survey of 1993. For black sigatoka severity, YLS scores were transformed using 1-YLS/TL and plotted against altitude for the years, 1993 and 2012.

Temperature change effect on key banana pests and black Sigatoka disease

The changes in pests and black Sigatoka disease incidence was obtained by subtracting the status of the pests, that is, banana weevil based on the damage levels, nematode populations and black Sigatoka disease at different elevations in the year 1991, from the pest and black Sigatoka status at the same elevation in the year 2013. Pearson's correlation analysis was performed between the resulting temperature changes and changes in weevil damage, nematode populations and sigatoka incidence at different elevations.

RESULTS

Temperature changes

The mean monthly minimum and maximum temperature changes in the major banana growing areas over the 22 years were site specific (Figures 1a to c and 2a to c). However, on the whole, minimum temperatures increased by approximately 1°C in sites which lied within the altitudes of 1400 and 1800 masl (Figure 1b and c).

Weevil damage

Generally, weevil damage in 2012 was higher than in 1993. The level of weevil damage was higher at lower altitudes than at higher altitudes. Unlike in 1993, banana corms were observed to be damaged by weevils even at highest altitudes (1800 masl) in the year 2012. But the extent of the damage was lower (< 1%) as compared to the rest of the altitudes (Figure 3).

Nematode assessment

P. goodeyi, *R. similis*, *H. multicinctus* and *Meloidogyne* spp. were the common nematode species found to be present in the diagnostic survey of 2012 as was reported in 1993 (Kashaija et al.,1994) (Table 1). In 1993, *R. similis* was present at altitudes between 1000 and 1300 masl and absent at altitudes between 1300 and1800 masl. Data collected in 2012 shows that *R. similis* was identified at all altitudes including 1800 masl. Although, *H. multicinctus* was present in all altitudes at both periods of assessment, there was significant increase in its populations at elevations above 1300 masl over the 20 year period. Populations of *P. goodeyi* did not change at higher elevations over the 20 year period.

Black Sigatoka disease assessment

In the year 2012, black Sigatoka disease was observed to be present in all the altitudes. This was not the case for the year 1993 (Figure 4) (Tushemereirwe, 1996). The presence of black sigatoka disease in higher altitudes (> 1400 masl) was confirmed by the PCR results

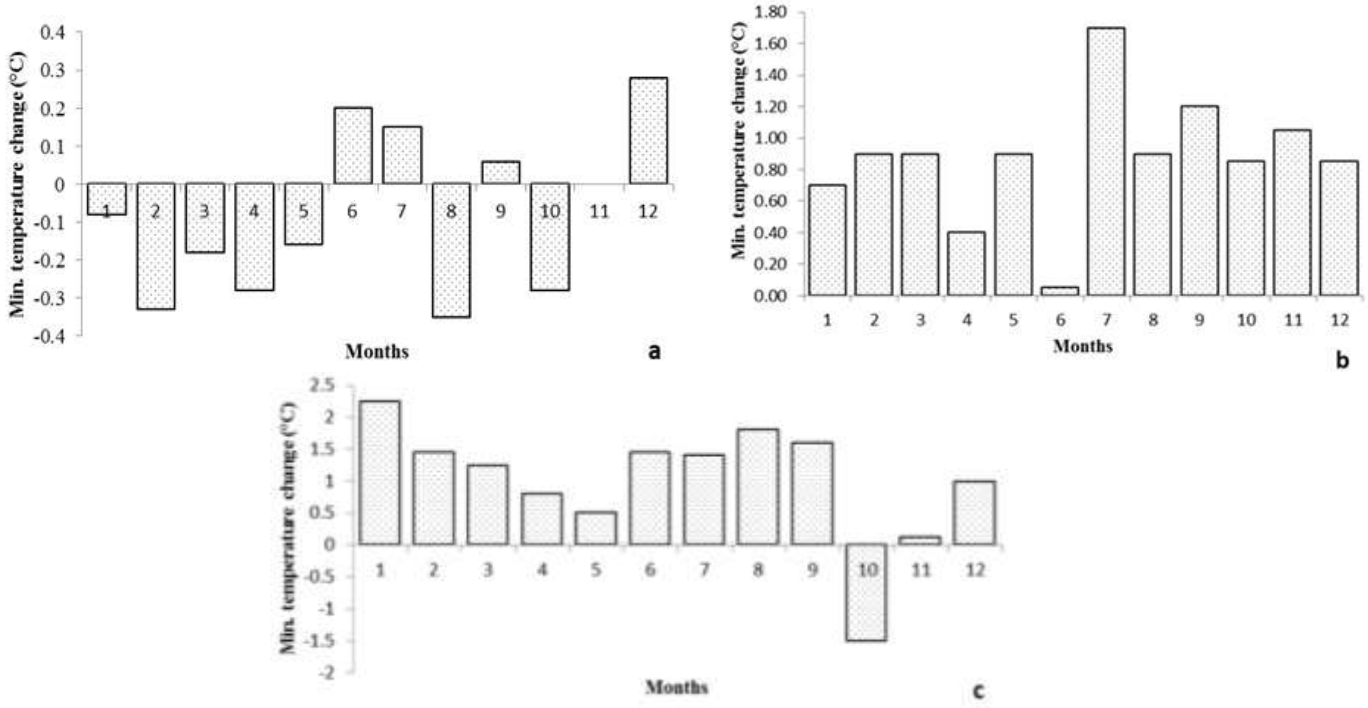

Figure 1. a to c: Mean monthly minimum temperature changes at different altitudes (a: 1200; b: 1400; c: 1800 masl) from 1991 to 2013 in banana growing areas. 1-12 = January to December.

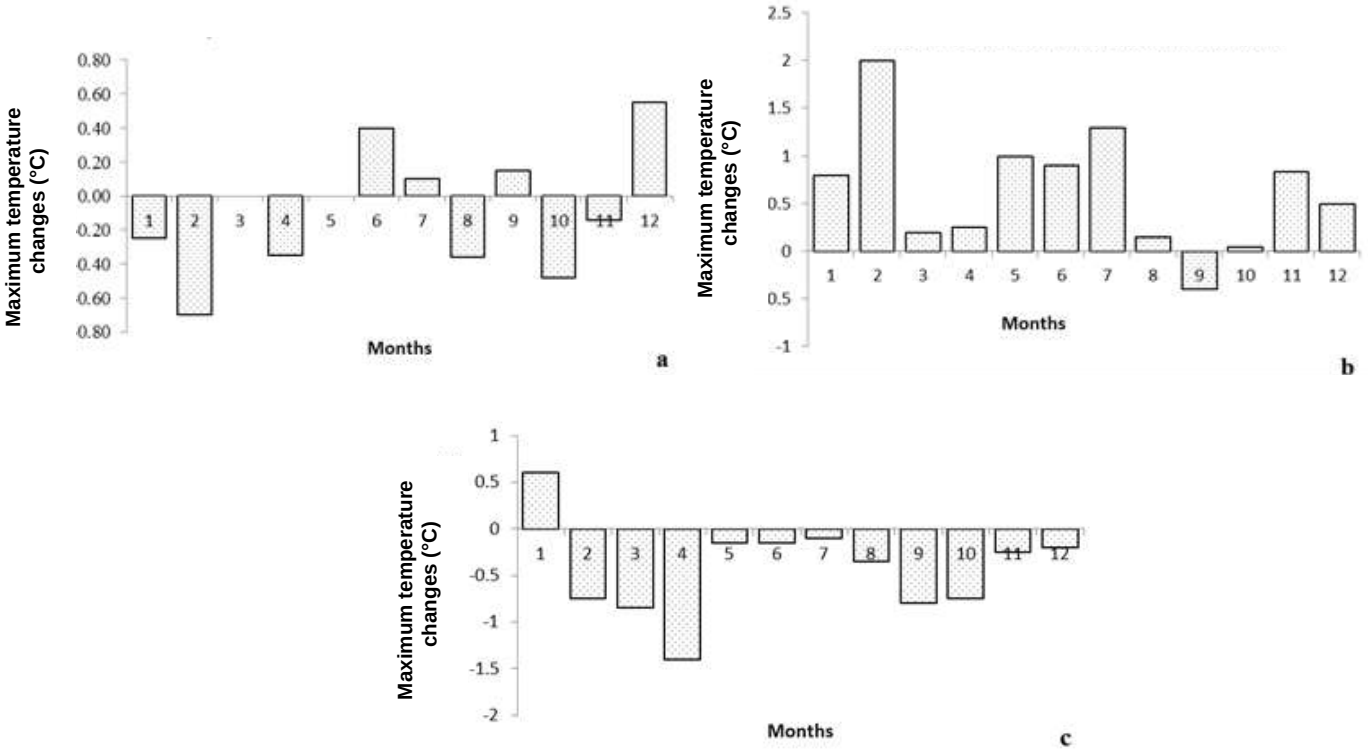

Figure 2. a to c. Mean monthly maximum temperature changes at different altitudes (a: 1200; b: 1400; c: 1800 masl) from 1991 to 2013 in banana growing areas.1 to 12 = January to December.

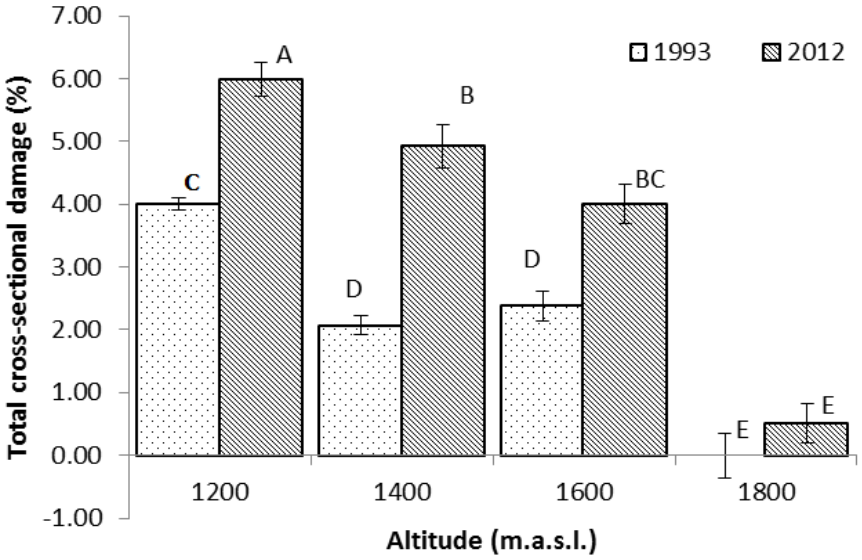

Figure 3. Proportions for total cross sectional weevil damage (%) at different elevations. Bars with same letters are not significantly different.

for most of the leaf samples obtained from the higher altitudes (Figure 5). This indicates that black Sigatoka disease has now spread to higher altitudes in the last 20 years.

Temperature change effect on incidence and distribution of the key banana pests and black Sigatoka disease

Results from the correlation analysis show that changes in black Sigatoka disease and *R. similis* populations were significantly and positively correlated to change in minimum temperature. On the other hand, change in maximum temperature positively correlated with the key banana pests and black Sigatoka disease. But only change in weevil damage was significantly and positively correlated with change in maximum temperature (Table 2). The areas that were not favorable at present due to low temperature may become favorable with rise in temperature (Das et al., 2011). Increased temperatures accelerate the development of some pests, resulting in more cycles of generations and crop damage per year (Awmack et al., 1997).

DISCUSSION

Temperature and moisture conditions in both air and soil are important for pathogen and insect survival, development and distribution. According to Rosenzweig et al. (2000), a change in temperature is significant enough to influence the insect populations and disease incidence as well as their distribution. It may influence the physiology, abundance, phenology and distribution of the insect pests (Lastuvka, 2009) and pathogenicity of fungal diseases (Lindner et al., 2010). This may explain the increase in nematode populations, weevil damage and black Sigatoka severity and distribution over time in different altitudes observed in this study, which were also strongly correlated with the increase in temperature. Nematode species like *R. similis*, *Melloidogyne* spp. and *H. multicinctus* are no longer limited to certain altitudes as it was earlier reported by Speijer et al. (1994) and Kashaija et al. (1994), suggesting that altitudes above 1300 masl appear to be favorable for the growth and development of these nematodes. Similarly, black Sigatoka disease which was previously limited to 1400 masl (Tushemereirwe, 1996), was confirmed at 1800 masl. This indicates that black Sigatoka disease has now spread to higher altitudes in the last 20 years.

The banana weevil damage was higher in low altitude areas than in highland areas (Njau et al., 2011). Hence, weevils were not a problem beyond 1500 masl (Gold and Messiaen, 2000). Data of this study shows that on the contrary, weevil damage was observed at an altitude of 1800 masl in the year 2012. This suggests that higher altitudes are becoming conducive for the growth and development of banana weevils. Although, the weevil damage changes were only significantly related to the maximum temperature changes over time, increased temperatures accelerate the development of some pests, resulting in more cycles of generations

Table 1. Mean counts of banana nematodes per 100 g of roots at different elevations.

Elevation (masl)	Nematode species per 100 g of root sample							
	R. similis		***H. multicinctus***		***Meloidogyne* spp.**		***P. goodeyi***	
	Year							
	1993	**2012**	**1993**	**2012**	**1993**	**2012**	**1993**	**2012**
>1000 - 1100	6480 (8.78)	2122 (7.66)	31960 (10.37)	5351 (8.59)	1430 (7.27)	8 (2.21)	680 (6.52)	0 (0.00)
>1100 - 1200	1440 (7.27)	235(5.46)	4860 (8.49)	1017 (6.93)	380 (5.94)	39 (3.69)	2640 (7.88)	661 (6.49)
>1200 - 1300	1110 (7.01)	388 (5.96)	4530 (8.42)	2750 (7.92)	124 (4.83)	172 (5.15)	10740(9.28)	1653 (7.41)
>1300 - 1400	0 (0.00)	34 (3.56)	120 (4.8)	2034 (7.62)	460 (6.13)	34 (3.56)	18430 (9.82)	1989 (7.60)
>1400 - 1500	0 (0.00)	15 (2.79)	160 (5.08)	259 (5.56)	0 (0.00)	9 (2.32)	7800 (8.96)	10103 (9.22)
>1500 - 1600	0 (0.00)	354 (5.87)	20 (3.04)	93 (4.55)	0 (0.00)	19 (2.98)	16770 (9.73)	10178 (9.23)
>1600	0 (0.00)	95 (4.57)	0 (0.00)	34 (3.55)	0 (0.00)	1 (0.88)	25200 (10.13)	12076 (9.40)

Values in brackets are the log transformation (Ln (x+1)) of the number of nematodes per 100 g of roots. Source: Diagnostic survey data: Kashaija (1996).

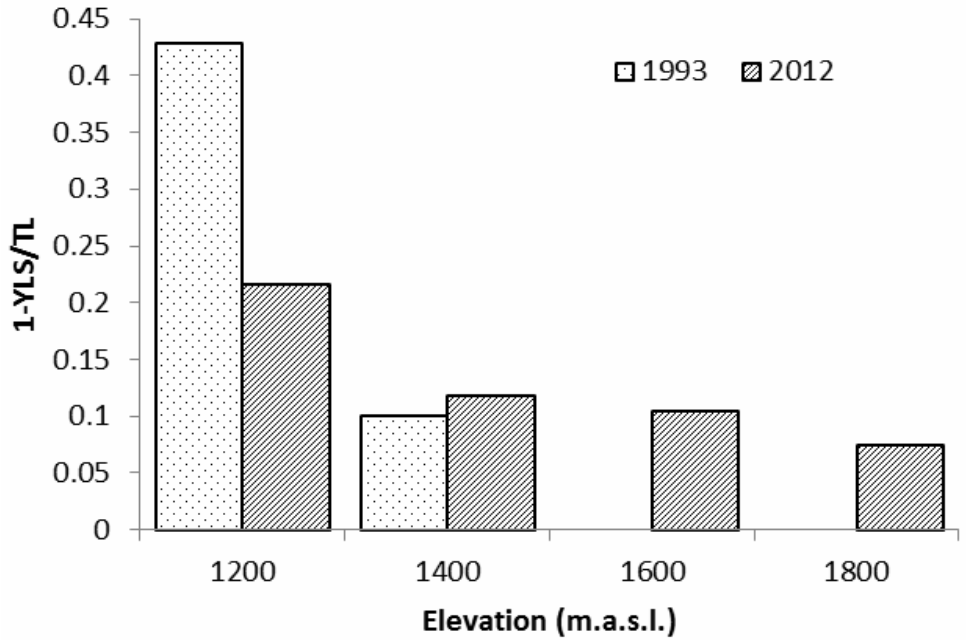

Figure 4. Incidence of black Sigatoka disease at different elevations. YLS = Youngest leaf spotted; TL = total number of functional leaves.

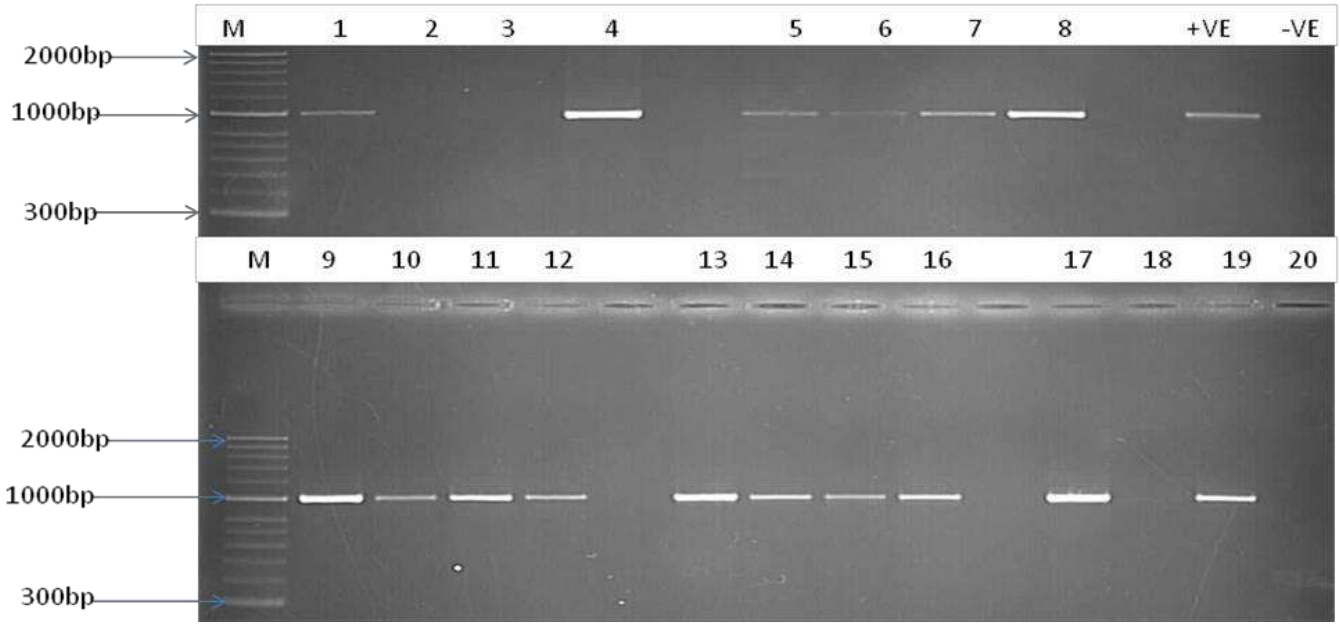

Figure 5. PCR results for DNA extracted from leaf samples to confirm the presence of black sigatoka disease. Upper panel; M, Molecular ladder 1 Kb; lanes 1 to 4 are samples from Bushenyi (1300 masl); lanes 5 to 8 are samples from Mbarara (1600 masl). Lower panel; M, molecular ladder 1 kb; lanes 9 to 12 are samples from Kabale (1800 masl); lanes 13 to 16 are samples from Kasese (1800 masl) and lanes 17 to 20 are samples from Kawanda (1200 masl).

Table 2. Correlation coefficient between changes in black Sigatoka disease, banana weevil damage, banana nematode populations, minimum and maximum temperatures

	T_{min} change	Change in weevil damage	BSD Change	RS_CH	HM_CH	Ms_CH	PG_CH	T_{max} change
Tmin change	1							
Change in weevil damage	-0.2110	1						
BSD Change	0.9825	-0.0280	1					
RS_CH	0.9970	-0.2917	0.8884	1				
HM_CH	0.9978	-0.1632	0.9473	0.9863	1			
Ms_CH	0.9976	-0.1615	0.9472	0.9862	0.9998	1		
PG_CH	-0.9993	0.1035	-0.8148	-0.5310	-0.6166	-0.6158	1	
Tmax change	0.1401	0.9383	0.3222	0.0634	0.2059	0.2077	-0.1777	1

Tmin = Minimum temperature; Tmax = maximum temperature; BSD = Black sigatoka; RS_CH= *R. similis* change; HM_CH= *H. multicinctus* change; Ms_CH= *Meloidogyne* spp. change; PG_CH = *P. goodeyi* change.

and crop damage per year (Awmack et al., 1997).

Conclusion

Over the last 20 years, temperature has increased significantly to influence changes in populations of key banana pests and diseases in major banana growing areas of Uganda. Banana weevils, destructive banana nematodes and black Sigatoka have increased in populations and damage levels. This was also confirmed at very high elevations where they have never occurred before. Therefore, strategies for management of key banana pests and disease epidemics likely to be influenced by changes in climate should be re-examined to take care of the new dynamics.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

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